AD 697 178

DEVELOPMENT OF IMPROVED TITANIUM ARMOR

Paul A. Farrar

New York University
New York, New York

15 August 1969

AD 697178

AD

AMMRC CR 69-16

DEVELOPMENT OF IMPROVED TITANIUM ARMOR

FINAL REPORT

by

P. A. Farrar

August 1969

Materials Engineering Division
Army Materials and Mechanics Research Center
Watertown, Massachusetts 02172

Contract No. DA-19-066-AMC-267 (T)

New York University
School of Engineering and Science
University Heights, New York, N.Y. 10453

Research Division
ARMY MATERIALS AND MECHANICS RESEARCH CENTER
WATERTOWN, MASSACHUSETTS 02172

17

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

Mention of any trade names or manufacturers in this report shall not be construed as advertising nor as an official indorsement or approval of such products or companies by the United States Government.

DISPOSITION INSTRUCTIONS

Destroy this report when it is no longer needed.
Do not return it to the originator.

DEVELOPMENT OF IMPROVED TITANIUM ARMOR

Final Report
AMMRC CR 69-16

by

P.A. Farrar

August 1969

Materials Engineering Division
Army Materials and Mechanics Research Center
Watertown, Massachusetts 02172

D/A Project No. IA22401A110
AMCMS Code No. 5025.11.842

Army Materials and Mechanics Research Center
Watertown, Massachusetts 02172

Table of Contents

Foreword

This report was prepared by the School of Engineering and Science, Research Division under U.S. Army Contract No. DA-19-066-AMC-267 (T). The contract was administered under the Army Materials and Mechanics Research Center, Watertown, Massachusetts, with Dr. Dino J. Papetti and Joseph L. Sliney serving as technical supervisors.

Abstract

This investigation was undertaken in order to determine the metallurgical factors which affect the ballistic properties of titanium, and to develop base materials with increased ballistic resistance. The use of the dual hardness principle was investigated in an attempt to use the intermetallic compound TiNi as one component in a roll bonded alloy.

It appears that the Widmanstätten structure stretched in the direction of rolling offers an easy path for fracture under ballistic impact. TiNi was not found to be suitable for dual hardness armor.

I. Introduction

This investigation was divided into seven phases as follows:

I. A detailed metallographic examination of alpha, alpha-beta and beta alloys was to be made on material which was subjected to ballistic tests with .30 AP projectiles. From this investigation it was hoped that some understanding of the metallurgical factors influencing the mode of ballistic failure will be deduced, i.e. what the factors are which determine whether a material fails by plug formations, delamination or spalling.

2. The titanium-6 aluminum-4 vanadium alloy was to be tested at constant energy ballistic tests at two energy levels. Projectiles of various weights are to be used in order to vary the velocity of the projectile without changing the energy. The alloy was to be tested in both the alpha-beta and beta heat treatments to see if there is any variation of the method of failure at constant energy as the speed of deformation resulting from impacting speed is varied.

3. An investigation was to be made of the possibility of using the compound TiNi for dual hardness armor purposes. Compositions of TiNi in the range 57-60 wt% Ni were to be studied, to determine if suitable higher hardness dual armor would be developed.

4. In conjunction with phase 3 an examination was to be undertaken of samples of steel bonded to titanium which are being supplied by AMMRC to see if ways could be found to produce a metallurgically sound bond between steel and titanium.

5. An attempt was to be made to produce compressive stresses in Ti-6Al-4V plates by low temperature heat treatment. This was to be undertaken to see if the pressure of the Ti_3Al phase could be used to produce compressive strains in the alloy and thus vary the ballistic impact resistance of the material.

6. An attempt was to be made to obtain the electron probe chemical analyses of the alpha and beta phases of annealed Ti-6Al-4V. Following this an ingot of the alpha and the beta composition was to be melted and fabricated to plate for ballistic testing. In this way it was hoped that it could be learned whether two phase or single phase alloys have inherently the better resistance to ballistic impact.

7. Titanium alloys were to be heat treated so as to produce a structure which would undergo martensitic deformation upon ballistic impact. From these tests it was hoped to see if the martensitic deformation would allow the spreading of the impact energy rapidly over a larger area of the material thereby increasing the ballistic impact absorbing property of the material.

II. Results

Results obtained are described in the following account:

A. Phase 1. - Metallographic Examination of Ballistic Impacts.

Examination of Ti-6Al-4V subjected to ballistic attack was made. Those specimens showing delamination were found to fracture along the direction of the deformed alpha and beta phases. It is not certain whether

fracture occurred along the α-β interface or in the beta. Work reported at the International Titanium Conference of 1968 indicated that void formation occurs at α-β interfaces beyond the ultimate tensile strength (1). Nevertheless, it would appear that the Widmanstätten structure stretched in the direction of rolling offered an easy path for fracture under ballistic impact.

Since the stress applied by the impacting projectile would, in general, tend to produce fracture approximately parallel to the plate surface it would be desirable, if possible, to eliminate the oriented structure. This could be done by heat treatment which would recrystallize the worked structure and possibly produce an equiaxed structure.

Alternately, since fracture occurs either along the beta between alpha particles or along the α-β interfaces, delamination would be reduced and plug formation made more likely if the alpha platelets could be oriented in directions perpendicular or nearly perpendicular to the rolled surface. A number of orientations of alpha can form from beta. Possibly those orientations most nearly perpendicular to the rolled surface could be induced to form by imposing a thermal gradient perpendicular to the rolled surface. The gradient would be moved across the thickness until all the precipitating alpha had formed.

This type of treatment is complex and probability of success in improving reaction to ballistic impact is uncertain. It would be initially more desirable to try the more easily attained equiaxed alpha structure with variations of size and amount of alpha.

B. Phase 2 - Constant Energy Ballistic Tests

Heat treatment of Ti-6Al-4V plates and the preparations of sample non-standard ballistic projectiles were completed. The projectiles were sent to AMMRC for testing.

C. Phases 3 & 4 - Dual Hardness Titanium Armor

Considerable improvement has been obtained in ballistic impact resistance of steel by the use of dual hardness armor (2). The steel facing the projectile has the higher hardness. The projectile and the high hardness steel shatter on impact and the softer ductile backing prevents the high hardness material from becoming shrapnel. A hardness of RC 60 or higher is apparently required in the outside material.

It is of interest to determine whether such improved behavior can be obtained in titanium. Commercial titanium alloys cannot be heat treated to the high levels required in steel for improved behavior. The intermetallic compound TiNi can be heat treated to RC 60 values when sufficient Ni is used (3).

In order to be used this intermetallic compound must be prepared as a plate which would then be roll bonded to a more ductile Ti alloy backing. It has been found (4) that alloys of 59-62 pct Ni, when heated to 1000°C and water quenched, attained hardness of RC 60 or above.

A fifty pound heat of TiNi, 59% Ni, was melted by consumable arc melting techniques. Although considerable difficulty had been encountered in trying to forge this material by previous investigations (3,4), it was hoped that if sufficient holding time were used prior to the forging operation that this material might be successfully worked. However, after 6 hours holding time at 1600-1900°F the ingot cracked upon initial forging attempts at 1900°F.

Following this, 50 gram buttons of 54, 55, 56, 57 and 58 pct. nickel TiNi alloys were prepared by arc melting. Attempts were made to

deform these alloys by rolling at 900°C. It was found that all of these compositions could be successfully rolled at this temperature. Rockwell C hardness values were taken on these alloys following quenching from 1000°C-2 hours. The hardnesses obtained were as follows: Ti-54% Ni: 27 RC; Ti-55% Ni: 27 RC; Ti-56% Ni: 38 RC; Ti-57% Ni: 45 RC; Ti-58% Ni: 53 RC.

An additional 6-pound heat of Ti-59% Ni alloy was melted by consumable arc melting and a 1/2-inch thick section of the as-cast ingot was prepared. This section was heat treated to RC 60 and then tested in ballistic impact. The purpose of this test was to see if the high hardness TiNi material would shatter the projectile when ballistically impacted. It was found by testing at AMMRC that the RC 60 TiNi did not shatter the armor piercing projectile and that the Ti-Ni plate was pierced. Thus TiNi does not appear to be suitable for the dual hardness armor approach.

Another method of producing light dual hardness armor is to use a hardened steel face with a titanium backing. This approach was under investigation by AMMRC personnel (5). However, difficulties were encountered in the bonding of the steel to the titanium backing. The procedure was to use an intermediate layer of V between the steel and the Ti. This intermediate layer is necessary in order to prevent the formation of brittle low melting TiFe during roll bonding.

Upon rolling at 1900°F, however, it was found that, although the Ti apparently bonded to the V, no bond was formed between the steel and the vanadium. Examination of the Ti-V interface indicated that a good metallurgical bond did exist between the two materials. However, the steel-V interface did not show any indications of bonding.

It was thought that this lack of bonding between the steel and the vanadium might be due to lower diffusion rates in the Fe-V system. Therefore it was suggested that the diffusion bonding and rolling temperatures be raised to 2200°F or above in order to promote more extensive diffusion across the steel-V interface.

Upon use of these higher temperatures it may be found that an intermetallic compound is formed at the steel-V interface. If this is the case, an intermediate layer of Cr may be used between V and the steel. Since the Cr σ phase forms very sluggishly, it is very unlikely that this phase would be encountered in this type of a process.

D. Phase 5 - Heat Treatment to Produce Compressive Stresses

Ten plates supplied by AMMRC were heat treated and returned for ballistic testing. The treatment temperatures were 500°F, 600°F, 700°F, 800°F and 900°F. One series, A, was soaked for 24 hours followed by a water quench. Series B was soaked for 96 hours and then water quenched.

E. Phase 6 - Electron Probe Analysis of Alpha and Beta Phases

Ti-6Al-4V ballistically impacted plate was provided by AMMRC. By means of a Phillips probe the plate was analyzed for three conditions: as-rolled, 1725°F-16 hrs W.Q. and 1650°F-16 hrs. W.Q. The analysis is as follows:

	Beta	Alpha
As-rolled	3.3Al-5.2V	5.9Al-3.1V
1725°F-16 hrs. W.Q.	4.24Al-6.28V	5.12Al-4.4V
1650°F-16 hrs. W.Q.	4.4Al-5.17V	4.28Al-3.0V

It was expected that the analyses of the alpha and beta phases would vary with heat treatment. The data were compared with the Ti-Al-V phase diagram (6) and no match could be obtained for the composition of both phases for a tie line passing through the Ti-6Al-4V point. Consequently the beta phase composition for 1725°F was selected as that corresponding to the Ti-6Al-4V tie line, i.e. Ti-6.5V-5Al, and the alpha phase composition at this temperature was found to be Ti-6.5Al-2.5V.

These compositions were melted as 12 lb. ingots 3 3/4" in dia. and the ingots were forged to 1/2" thick plate at 1500°F. They were subsequently heat treated as follows:

Plate	β-transus	Plate #	Heat Treatment
β - Ti-5Al-6.5V	1700°F	1A	1700°F-15 min. W.Q. 1150°F- 1 hr. A.C.
		1B	1670°F-1/2 hr. W.Q. 1150°F- 1 hr. A.C.
α - Ti-6.25Al-2.5V	1875°F	2A	1725°F- 1 hr. W.Q. 1150°F- 1 hr. A.C.
		2B	1825°F- 1 hr. W.Q. 1725°F- 1 hr. W.Q. 1150°F- 1 hr. A.C.

The beta composition alloy, Ti-5Al-6.5V, was heat treated to produce an essentially all beta structure (1700°F solution treatment) and an α+β structure (1670°F solution treatment). The alpha composition alloy was heat treated to produce a transformed structure (plate 2B) and an all alpha structure (sample 2A). These plates are ready for testing and have been delivered to AMMRC.

F. Phase 7

Heat treatment of samples for this phase of the work was started.

References

1. H. Margolin, P.A. Farrar and M.A. Greenfield: "Thermo-Mechanical Strengthening of High Strength Titanium Alloys". Proceedings of the International Conference on Titanium, London, England, May 21-24, 1968. In press by Academic Press, New York, N. Y.

2. Private Communication - J. Sliney, Whittaker Corporation, West Concord, Massachusetts.

3. W.J. Buehler and R.C. Wiley: "The Properties of TiNi and Associated Phases". U.S.N. Ordnance Laboratory, White Oak, Maryland, No. TR 61-75.

4. Private Communication - R. Broadwell, TMCA, West Caldwell, New Jersey.

5. Private Communication - J. Sliney, Whittaker Corporation, West Concord, Massachusetts.

6. P.A. Farrar and H. Margolin: "The Titanium Rich Region of the Titanium-Aluminum-Vanadium System". Trans. AIME, 1961, V. 221, pp. 1214-1221.

AD ____________ Accession No. ____________
Materials Engineering Division, Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172

DEVELOPMENT OF IMPROVED TITANIUM ARMOR. P. A. Farrar, New York University, School of Engineering and Science, Research Division, New York, N. Y.

Final Report AMMRC CR 69-16, August 1969, 9pp., D/A Project 1A22401A110, AMCMS Code 5025.11.842. Unclassified Report. Contract No. DA-19-066-AMC-267 (T)

This investigation was undertaken in order to determine the metallurgical factors which affect the ballistic properties of titanium, and to develop base materials with increased ballistic resistance. The use of the dual hardness principle was investigated in an attempt to use the intermetallic compound TiNi as one component in a roll bonded alloy. It appears that the Widmanstätten structure stretched in the direction of rolling offers an easy path for fracture under ballistic impact. TiNi was not found to be suitable for dual hardness armor

NO DISTRIBUTION LIMITATIONS

UNCLASSIFIED

1. Titanium
2. Ballistic resistance
3. Titanium alloys

I. Farrar, P. A.
II. D/A Project 1A22401A110
III. AMCMS Code 5025.11.842

AD ____________ Accession No. ____________
Materials Engineering Division, Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172

DEVELOPMENT OF IMPROVED TITANIUM ARMOR. P. A. Farrar, New York University, School of Engineering and Science, Research Division, New York, N. Y.

Final Report AMMRC CR 69-16, August 1969, 9pp., D/A Project 1A22401A110, AMCMS Code 5025.11.842. Unclassified Report. Contract No. DA-19-066-AMC-267 (T)

This investigation was undertaken in order to determine the metallurgical factors which affect the ballistic properties of titanium, and to develop base materials with increased ballistic resistance. The use of the dual hardness principle was investigated in an attempt to use the intermetallic compound TiNi as one component in a roll bonded alloy. It appears that the Widmanstätten structure stretched in the direction of rolling offers an easy path for fracture under ballistic impact. TiNi was not found to be suitable for dual hardness armor

NO DISTRIBUTION LIMITATIONS

UNCLASSIFIED

1. Titanium
2. Ballistic resistance
3. Titanium alloys

I. Farrar, P. A.
II. D/A Project 1A22401A110
III. AMCMS Code 5025.11.842

AD ____________ Accession No. ____________
Materials Engineering Division, Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172

DEVELOPMENT OF IMPROVED TITANIUM ARMOR. P. A. Farrar, New York University, School of Engineering and Science, Research Division, New York, N. Y.

Final Report AMMRC CR 69-16, August 1969, 9pp., D/A Project 1A22401A110, AMCMS Code 5025.11.842. Unclassified Report. Contract No. DA-19-066-AMC-267 (T)

This investigation was undertaken in order to determine the metallurgical factors which affect the ballistic properties of titanium, and to develop base materials with increased ballistic resistance. The use of the dual hardness principle was investigated in an attempt to use the intermetallic compound TiNi as one component in a roll bonded alloy. It appears that the Widmanstätten structure stretched in the direction of rolling offers an easy path for fracture under ballistic impact. TiNi was not found to be suitable for dual hardness armor

NO DISTRIBUTION LIMITATIONS

UNCLASSIFIED

1. Titanium
2. Ballistic resistance
3. Titanium alloys

I. Farrar, P. A.
II. D/A Project 1A22401A110
III. AMCMS Code 5025.11.842

AD ____________ Accession No. ____________
Materials Engineering Division, Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172

DEVELOPMENT OF IMPROVED TITANIUM ARMOR. P. A. Farrar, New York University, School of Engineering and Science, Research Division, New York, N. Y.

Final Report AMMRC CR 69-16, August 1969, 9pp., D/A Project 1A22401A110, AMCMS Code 5025.11.842. Unclassified Report. Contract No. DA-19-066-AMC-267 (T)

This investigation was undertaken in order to determine the metallurgical factors which affect the ballistic properties of titanium, and to develop base materials with increased ballistic resistance. The use of the dual hardness principle was investigated in an attempt to use the intermetallic compound TiNi as one component in a roll bonded alloy. It appears that the Widmanstätten structure stretched in the direction of rolling offers an easy path for fracture under ballistic impact. TiNi was not found to be suitable for dual hardness armor

NO DISTRIBUTION LIMITATIONS

UNCLASSIFIED

1. Titanium
2. Ballistic resistance
3. Titanium alloys

I. Farrar, P. A.
II. D/A Project 1A22401A110
III. AMCMS Code 5025.11.842

AD______________ Accession No.______________

Materials Engineering Division, Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172

DEVELOPMENT OF IMPROVED TITANIUM ARMOR. P. A. Farrar, New York University, School of Engineering and Science, Research Division, New York, N. Y.

Final Report AMMRC CR 69-16, August 1969, 9pp., D/A Project 1A22401A110, AMCMS Code 5025.11.842. Unclassified Report. Contract No. DA-19-066-AMC-267 (T)

This investigation was undertaken in order to determine the metallurgical factors which affect the ballistic properties of titanium, and to develop base materials with increased ballistic resistance. The use of the dual hardness principle was investigated in an attempt to use the intermetallic compound TiNi as one component in a roll bonded alloy. It appears that the Widmanstätten structure stretched in the direction of rolling offers an easy path for fracture under ballistic impact. TiNi was not found to be suitable for dual hardness armor

NO DISTRIBUTION LIMITATIONS

UNCLASSIFIED

1. Titanium
2. Ballistic resistance
3. Titanium alloys

I. Farrar, P. A.
II. D/A Project 1A22401A110
III. AMCMS Code 5025.11.842

AD______________ Accession No.______________

Materials Engineering Division, Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172

DEVELOPMENT OF IMPROVED TITANIUM ARMOR. P. A. Farrar, New York University, School of Engineering and Science, Research Division, New York, N. Y.

Final Report AMMRC CR 69-16, August 1969, 9pp., D/A Project 1A22401A110, AMCMS Code 5025.11.842. Unclassified Report. Contract No. DA-19-066-AMC-267 (T)

This investigation was undertaken in order to determine the metallurgical factors which affect the ballistic properties of titanium, and to develop base materials with increased ballistic resistance. The use of the dual hardness principle was investigated in an attempt to use the intermetallic compound TiNi as one component in a roll bonded alloy. It appears that the Widmanstätten structure stretched in the direction of rolling offers an easy path for fracture under ballistic impact. TiNi was not found to be suitable for dual hardness armor

NO DISTRIBUTION LIMITATIONS

UNCLASSIFIED

1. Titanium
2. Ballistic resistance
3. Titanium alloys

I. Farrar, P. A.
II. D/A Project 1A22401A110
III. AMCMS Code 5025.11.842

AD______________ Accession No.______________

Materials Engineering Division, Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172

DEVELOPMENT OF IMPROVED TITANIUM ARMOR. P. A. Farrar, New York University, School of Engineering and Science, Research Division, New York, N. Y.

Final Report AMMRC CR 69-16, August 1969, 9pp., D/A Project 1A22401A110, AMCMS Code 5025.11.842 Unclassified Report. Contract No. DA-19-066-AMC-267 (T)

This investigation was undertaken in order to determine the metallurgical factors which affect the ballistic properties of titanium, and to develop base materials with increased ballistic resistance The use of the dual hardness principle was investigated in an attempt to use the intermetallic compound TiNi as one component in a roll bonded alloy It appears that the Widmanstätten structure stretched in the direction of rolling offers an easy path for fracture under ballistic impact TiNi was not found to be suitable for dual hardness armor

NO DISTRIBUTION LIMITATIONS

UNCLASSIFIED

1. Titanium
2. Ballistic resistance
3. Titanium alloys

I. Farrar, P. A.
II. D/A Project 1A22401A110
III. AMCMS Code 5025.11.842

AD______________ Accession No.______________

Materials Engineering Division, Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172

DEVELOPMENT OF IMPROVED TITANIUM ARMOR. P. A. Farrar, New York University, School of Engineering and Science, Research Division, New York, N. Y.

Final Report AMMRC CR 69-16, August 1969, 9pp., D/A Project 1A22401A110, AMCMS Code 5025.11.842. Unclassified Report. Contract No. DA-19-066-AMC-267 (T)

This investigation was undertaken in order to determine the metallurgical factors which affect the ballistic properties of titanium, and to develop base materials with increased ballistic resistance. The use of the dual hardness principle was investigated in an attempt to use the intermetallic compound TiNi as one component in a roll bonded alloy. It appears that the Widmanstätten structure stretched in the direction of rolling offers an easy path for fracture under ballistic impact. TiNi was not found to be suitable for dual hardness armor

NO DISTRIBUTION LIMITATIONS

UNCLASSIFIED

1. Titanium
2. Ballistic resistance
3. Titanium alloys

I. Farrar, P. A.
II. D/A Project 1A22401A110
III. AMCMS Code 5025.11.842

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) New York University Engineering Research Division	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

Development of Improved Titanium Armor

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report - 15 August 1969

5. AUTHOR(S) (First name, middle initial, last name)

Paul A. Farrar

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
August 1969	10	6

8a. CONTRACT OR GRANT NO. DA-19-066-AMC-267 (T) b. PROJECT NO. D/A Project 1C 024401A328 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) AMMRC CR 69-16 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Army Materials and Mechanics Research Center

13. ABSTRACT

This investigation was undertaken in order to determine the metallurgical factors which affect the ballistic properties of titanium, and to develop base materials with increased ballistic resistance. The use of the dual hardness principle was investigated in an attempt to use the intermetallic compound TiNi as one component in a roll bonded alloy.

It appears that the Widmanstätten structure stretched in the direction of rolling offers an easy path for fracture under ballistic impact. TiNi was not found to be suitable for dual hardness armor.

DD FORM 1 NOV 65 1473

Unclassified
Security Classification

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT

Security Classification